RESEARCH PROPOSAL

Joint Project with the Flexible and Geotechnical Technical Oversight Committees

EVALUATION OF INTELLIGENT COMPACTION TECHNOLOGY FOR DENSIFICATION OF ROADWAY SUBGRADES AND STRUCTURAL LAYERS

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1.0 PROBLEM STATEMENT

The quality of pavement construction is dependent on getting adequate compaction throughout the supporting embankment and pavement layers. Historically, the support quality of compacted soils and pavement layers has been specified as a function of the relative compaction density. This density varies with several factors including compaction energy, material characteristics, temperature, water content, etc. for a given material. The objective of achieving a specified density is to ensure a minimum layer stiffness and strength for compacting the upper layers and reducing detrimental long-term material property changes.

In current practice, achieving adequate density is judged by either visual means through proof rolling (typical for embankments in Wisconsin) or discrete in-place density measurements made by nuclear density gauges or other devices. The roller pattern to achieve this target density is determined at the beginning of the project through a control strip and then used throughout the project length. Many factors can change within the length of a project that can cause over-compaction (degradation of material) or not achieving the specified density, requiring the area to be reworked, removed, or the issuance of a penalty to the contractor.

Intelligent Compaction (IC) is an emerging technology that monitors layer stiffness during compaction by instrumenting the roller to measure its reaction to the material being compacted. IC gives the contractor the opportunity to continuously monitor and document layer stiffness at the time of compaction, producing more uniformly-compacted pavement layers, and allowing real-time compaction modifications based on response outputs. The output from this technology also provides documentation for owner and contractor management regarding material quality of all pavement layers. Thus, the technology has potential to improve density and quality, having a positive impact on pavement warranty and design-build contracts, as well as traditional contracts.

Warranty contracts transfer more risk to the contractor. Contractor and agency personnel do have concern over the relative compaction of lower material layers because the stiffness of the support layer influences the compaction and service life of the upper pavement layers. The higher the uncertainty regarding layer support, the higher the bid price as contractors begin to accept more risk for pavement performance through a warranty period. In summary, implementation of IC technology has the potential of lowering construction costs, improving overall quality, reducing variability, and enhancing the service life of pavement systems by providing the contractor documentation of layer stiffness levels and minimizing the potential for de-compaction and degradation of all pavement layers.

2.0 RESEARCH OBJECTIVES

The overall goal of this project is to collect information and data on the use of IC technology to allow the Wisconsin Department of Transportation (WisDOT) to make an informed decision on any useful application of the IC technology – its validity and accuracy. To accomplish this overall goal, three objectives will need to be accomplished within this study, which are listed below:

1. Identify the advantages and limitations of the IC technology.
2. Determine the material types and conditions that might cause inaccurate decisions or output from the IC roller (e.g., the accuracy of the outputs regarding layer stiffness). As part of this objective, the output values or responses from the IC rollers, that are manufacturer dependent, will be correlated to density and modulus of the material during the compaction process.
3. Provide recommendations to WisDOT on the use and implementation of IC technology for pavement construction.

3.0 BACKGROUND AND SIGNIFICANCE OF WORK

IC technology has been in existence for several years, and provides real-time, in-place material stiffness data that can be used by roller operators to make better decisions. The use of IC technology as a viable construction quality measure has increased over the past decade. Over 15 State and Federal agencies have sponsored demonstration projects or case studies to date. Multiple manufacturers (Ammann, Bomag, Caterpillar, Geodynamic, and Sakai) now build IC equipment with varying outputs and controls (see Figures 1 through4). These manufacturers have fully equipped rollers, but also have instrumentation kits that can be attached to existing vibratory rollers. NCHRP Project 10-65 provides a brief description on the operation, measurement system, and outputs for the different IC rollers (Von Quintus, et al., 2006).

Figure 1. BOMAG Asphalt Manager IC Roller that was used on NCHRP Project 10-65.

Figure 2. AMMANN IC Roller that was used on NCHRP Project 10-65.

Figure 3. Caterpillar IC Roller that was used on NCHRP Project 10-65.

Figure 4. Vibratory that was instrumented and used on NCHRP Project 10-65.

The three systems that have been used more extensively include the Bomag Asphalt Manager and Vari-Control system, the Onboard Density Measuring System (ODMS) patented by Pennsylvania State University, and the Continuous Compaction Control (CCC) system developed by Geodynamik. These systems offer real time pavement quality measurement, and use accelerometers to measure parameters of the compactor's vibratory signature. Other sensors are also used to gain information about the pavement, and used to estimate pavement quality via layer stiffness values. The true test of this "intelligent compaction" system is whether it saves time (fewer passes), improves uniformity of the layer, and produces accurate, consistent readings that can be used in a decision-making process by the contractor and WisDOT.

IC rollers have been used on various demonstration projects and case studies throughout the U.S. Minnesota DOT, FHWA, and NCAT all recently sponsored demonstrations and workshops on the use of IC rollers. Other agencies where case studies have been completed include Alabama, Florida, Iowa, Maine, Oklahoma, Virginia, Texas, and Wisconsin, to name a few. FHWA has also developed a strategic plan (Horan et al., 2005) to implement IC technology within the U.S., which includes a systematic procedure to encourage State agencies and industry to expedite the implementation process. Several agencies including Iowa, Louisiana, Minnesota, New Jersey, North Carolina, Virginia, etc. are conducting field and laboratory studies to evaluate IC technology and to develop specifications for pilot projects.

The MnDOT demonstration at the Minnesota Road Research (MnROAD) test track used the BOMAG CCC system and other NDT devices—Dynamic Cone Penetrometer (DCP), Geogauge, light weight deflectometer (LWD), —to independently measure soil properties at each test point. In general, it was found that the moisture content in the soil greatly influenced the compaction process and the modulus measurement. The study suggests future demonstration projects on "real-world" construction projects.

More recently, IC rollers (Bomag, Caterpillar, Ammann, and an instrumented vibratory roller) were used in NCHRP Project 10-65 for controlling and accepting HMA mixtures and unbound pavement layers and comparing their responses to modulus and density values measured by traditional density measuring devices and other nondestructive testing devices (Von Quintus, et al., 2006). The type of materials included crushed aggregate bases, high and low plasticity clays, and HMA base mixtures. Overall, the IC rollers did detect dense and less dense areas and their output was found to correlate with other NDT values. Conversely, the IC rollers did bridge some localized weak areas or anomalies in both HMA and unbound aggregate layers.

Figure 5 compares the modulus values before and after IC rolling, as measured by different NDT devices. As shown, most of the modulus values consistently increased after IC rolling. Figure 6 compares the coefficient of variation of the average modulus values before and after IC rolling. The variability in the modulus values did decrease in selected areas, but not in all areas. Densification curves were also prepared and used to evaluate changes in the measured responses of the IC roller to increases in density of the HMA layer. Figure 7 compares the density and Evib readings, while Figure 8 is an example of the densification curves. The contractor's compaction operation included the use of two rollers to achieve the same density as the IC roller, confirming that the IC technology can be more efficient. Figure 8 also shows the benefit of using the Evib to determine when the correct number of passes has been used to reach density. This additional information during lift compaction would be a benefit to most roller operators to ensure that an adequate density or stiffness of the HMA mixture had been reached.

Seismic testing was also used to measure the modulus of HMA mixtures at the same points used to prepare the densification curves (Figure 8). The average seismic modulus measured in the control strip was 269 ksi, as compared to an average value of 239 ksi without the use of the IC roller. The seismic tests suggest a definite increase in the stiffness of the mixture, in addition to the increase in density. The one major issue that has yet to be resolved is correctly taking into account the effect of decreases in temperature on the increase in E_{vib} during compaction of the HMA lift or changes in moisture content of unbound layers.

The National Cooperative Highway Research Program (NCHRP) initiated project 21-09 in 2006 to determine the reliability of IC systems and to develop QA specifications for the application of IC in the compaction of unbound materials. The study is ongoing and has included an evaluation of three IC systems for soils—Ammann, Bomag, and Caterpillar—using field data. Findings to-date suggests smooth drum rollers are more reliable than sheet-foot rollers. A change in displacement amplitude of the roller proved to have a larger effect on soft clays than on granular materials. Soils properties such as modulus and penetration index are correlated to roller output for both subgrade clays and aggregate materials. Future tasks to be undertaken will result in the development of construction specifications for embankments and granular bases.

In summary, nearly all previous studies completed to-date have concluded that the use of IC rollers has many advantages and should be pursued as a contractor's quality control tool to monitor the compaction of pavement materials. However, there have been relatively few field and theoretical studies to determine the importance of the measured response parameters and confirm that the measured response relates to changes in density and stiffness of the material being compacted. Most studies have focused on the effect of increases in material compaction or density on the IC measured response and found good correlations between the IC output and density for a specific material and project. Fewer studies have focused on the effect of temperature, moisture and material condition on the responses and output from the IC measurement systems, in terms of reducing the risk of making an incorrect decision during construction. The WisDOT study will provide data to confirm the response measurements of the IC rollers to stiffness and density increases and identify limitations of the equipment – detection of localized anomalies or soft spots.

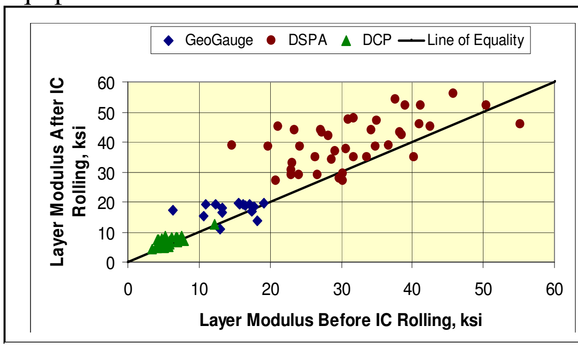


Figure 5. Comparison of modulus values measured with different NDT devices before and after IC rolling of an embankment soil.

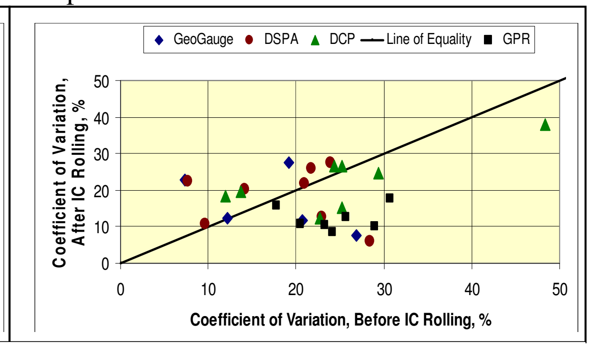


Figure 6. Uniformity of an embankment before and after IC rolling, determined from modulus measurements of other NDT devices.

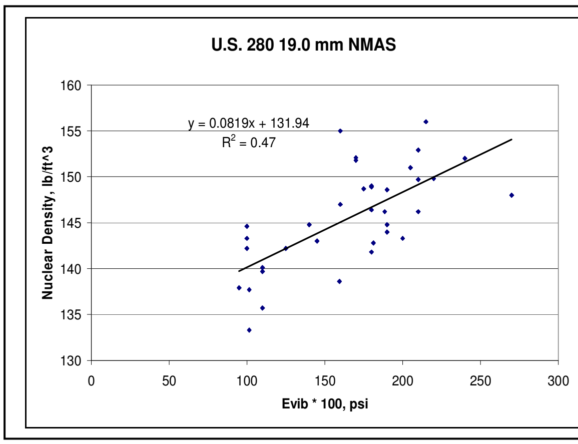


Figure 7. Comparison of the nuclear density readings to the E_{vib} values measured with the IC roller.

Figure 8. Example of a densification growth curve prepared from the IC roller demonstration and NDT test results.

4.0 BENEFITS FROM STUDY

Our project team foresees several major benefits from this study, which are listed below.

1. WisDOT can use the results in deciding whether the use of IC technology is beneficial to the Department by reducing construction costs and risks to the contractor and agency. Specifically, confirming some of the reported savings in compaction costs, while reducing the variability of density.
2. Results from this study will define those site conditions and properties of lower layers that have an effect on densification of the upper layers so that they can be considered during the construction process to minimize the occurrence of penalties imposed on the contractor and premature distress – saving maintenance costs. In other words, the contractor is able to make a better decision on the number of passes or the most efficient rolling pattern to achieve the target density at a minimum cost.
3. WisDOT can use the IC roller responses and output to determine the locations where point measurements may be needed for final acceptance of the pavement layer. In other words, strategically locate the more time consuming acceptance tests and reduce the number of tests without increasing WisDOT's risk of making a wrong decision; similar to the process that Washington DOT has implemented with infrared cameras.

4. WisDOT will have in-place data to document the relative stiffness or modulus of each layer during construction. Results will be applicable to the use of the new Mechanistic-Empirical Pavement Design Guide (MEPDG), which WisDOT is planning to implement, and can be used to confirm some of the input parameters used for structural design; tying mixture and structural design parameters to construction. These measured responses could reduce the laboratory testing costs for measuring the modulus of different materials.
5. Results from this study can also assist WisDOT in providing acceptance criteria to ensure that the final product will meet the design requirements. In other words, the decision-maker (contractor or WisDOT) will have real-time data to make the best and most cost-effective decisions to provide the greatest long-term benefits to WisDOT and the traveling public. The results from this study can also be extremely valuable to other agencies that plan to use this technology for controlling flexible pavement construction and HMA overlays, as well as considering the use of the MEPDG.

5.0 IMPLEMENTATION OF RESULTS INTO PRACTICE

An implementation plan will be developed and submitted along with the final report for this study. The implementation plan will include two major parts; a manual, prepared in WisDOT format, for use in making modifications to the FDM and construction specifications, and a training course for using IC technology to reduce risks of making a wrong decision by the contractor and agency personnel. Implementation of the results into practice will take time and will be dependent on the availability of these rollers in Wisconsin. An important point of this study is to confirm the adequacy of the attachments to existing vibratory rollers and demonstrate the measured responses for providing contractors with confidence in the measured responses in making real-time decisions regarding compaction of pavement materials.

A training course will be prepared specifically for use in Wisconsin. This training course will be developed so that industry and WisDOT can continue the educational process after this project has been completed. The training course will include fully operational IC rollers and the modification of existing rollers to include the IC attachments.

6.0 DETAILED WORK PLAN

The work plan described in this section consists of nine tasks, which are discussed below.

Task 1 Literature Review of IC Technology and Database

There are two major activities included under Task 1; a detailed literature review of IC technology and the development of a project database of IC use and findings. The proposed research will begin with a comprehensive literature search/review to establish the current state-of-the practice for using the IC technology. The project team will start with the information and review that was completed under NCHRP Project 10-65 (Von Quintus, et al., 2006). The literature search will focus on the more recent demonstration projects and case studies that have quantified the benefits, limitations, and problems encountered. The review will focus on (but not be restricted to) studies completed and specifications developed in the upper mid-western agencies.

Specifically, the Principal Investigator of NCHRP 9-21 and some of the pooled fund studies will be contacted within the first month of the study. In addition, each of the manufacturers will be contacted to determine where their IC rollers are being used and to obtain any updates on equipment modifications that might have been made. Mr. John D'Angelo and Lee Gallivan are individuals with FHWA that will be contacted individually, as well as other agency personnel that have been actively involved in the development of IC technology – as an example, Mr. John Siekmeier with the Minnesota DOT, which has a draft specification. Some of these are included in the list of references (see Sect. 12). In short, the literature review will aim to answer the following questions, as a minimum:

- What progress have other States in the U.S. and particularly those in the Midwest made with regard to evaluating and implementing IC technology?
- Does IC lead to better and more uniform compaction than conventional compaction methods?

- Is the effectiveness of this technology influenced by material parameters, such as subgrade type, moisture content in unbound layers, granular layers versus embankments, HMA mixtures (fine versus coarse gaded). The review will also focus on the recent demonstrations related to the reliability of NDT devices to measure the in-place moisture content of unbound materials.
- Are draft specifications and output criteria ("trigger values") developed by other agencies applicable for use in Wisconsin (e.g., Minnesota to name one)?

The literature will be completed within the first 3 months of the project, and all of the results and findings will be summarized in an interim task summary report. This document will present the critical factors or problems that have been defined from the demonstrations, case studies, and other projects completed regarding use of the IC technology. Both ARA and University of Wisconsin at Milwaukee (UWM) staff will be involved in the literature review. However, UWM will coordinate the review process to ensure that there is no duplication in reviewing reports, demonstrations, and case studies where the IC technology has been used. The literature review will be followed by the development of a database of IC use in other State and Federal agencies. ARA will be responsible for developing the database. It is expected that an excel type spreadsheet and database will be used to retain the information and data collected from this task, as well as from the field and laboratory tests. This subtask activity will be initiated and completed within the first quarter of the project.

Task 2 Coordinate with WisDOT and Contractors to Select Candidate Field Projects

Task 2 has two major activities; a kick-off meeting and contacts with pertinent WisDOT, industry, and manufacturer personnel. The task will begin with a meeting to present the results of our literature review, database, and project schedule. As part of this meeting, our project staff will request a listing of planned construction projects for 2008. This project listing will be used to select projects that fit within the work plan being developed under Task 3. The PI and Co-PI (see Section 10) will attend this initial meeting. After the candidate projects for the 2008 construction season have been tentatively selected for this project, a draft preliminary field work plan will be developed for use in our discussions with the contractors and WisDOT personnel. Knowing the specific projects will allow the draft preliminary work plan to be project specific and include more detail. This draft preliminary work plan will be prepared from the information included in our discussion of Task 3 below.

After this meeting, project staff will contact industry and WisDOT personnel, as well as equipment manufacturers, for planning the field work within the 2008 construction season. Two of the IC equipment manufacturers (Bomag and Caterpillar) have already been contacted in preparation of our proposal and both have agreed to lease their equipment for use on this project. We will also contact other equipment manufacturers to determine the availability and use of other IC rollers on selected projects. Contractors that have already been awarded projects will be contacted to determine their agreement to attach one of the IC kits to a roller being used on their project (similar to the vibratory roller that was instrumented on the Texas DOT project, see Figure 4). UWM will lead the coordination effort with WisDOT and contractor personnel.

Task 3 Develop Preliminary Field Work Plan

The purpose of Task 3 is to develop the field work plan and select the projects to be used under Task 5. The preliminary field work plan will be submitted in the interim report under Task 4. The TOC will have the opportunity to comment on the work plan prior to actually initiating the work plan.

Task 3 will begin with the project team developing the hypothesis between the IC roller response and stiffness or density of the material, as measured with other devices. The work plan will include specific projects, type of pavement, materials used in the project, number of sections within a project, and tests and frequency of tests. The preliminary work plan will be developed based on the projects tentatively selected and the initial coordination with the contractor for each project selected as a candidate under Task 2.

This part of our proposal provides a listing on the factors and features that will be considered in the work plan. Obviously the work plan may change depending on the findings from the literature review under Task 1. The type of tests and equipment that is planned for use in the field projects is included under Task 5.

Type of Pavement. The following types of pavements or construction projects will be considered to ensure that different materials and conditions are covered within the work plan.

1. Conventional flexible pavement structure so that the embankment, aggregate base, and HMA mixture compaction will be available from one project to observe the effect of potential soft areas on future layer placement and compaction. New pavement construction projects will be used to demonstrate the building of the layer modulus structure within flexible pavements. A total of 3 new flexible pavement projects are planned for use to ensure that the diversity of site conditions, materials and soils typically encountered in Wisconsin are included in the plan. Fewer projects would be better from a cost standpoint, if the projects selected have a sufficient diversity of conditions, materials and soils typically encountered in Wisconsin.
2. The other type of pavement will be an HMA overlay of an intact PCC or flexible pavement. A total of 2 HMA overlay projects are planned for use in this part of the field work plan; an HMA overlay of a flexible pavement and an HMA overlay of a PCC pavement.

IC Rollers. Different IC rollers are planned for use on each project to compare the variability in the measured responses and decisions made from the output from those responses. The work plan will include multiple IC rollers that can be scheduled for a project. In addition, the work plan will include the IC kits that can be attached to one of the rollers being used by the contractor on a day-to-day basis for the project. A minimum of two sections per layer is planned; the control or standard roller pattern being used by the contractor and a section for each IC roller used on the project. Multiple IC rollers mean multiple sections along each project. Each section or compaction zone will be about 300 to 500 feet in length. Replicate sections will be considered for each roller pattern.

Unbound Materials and Soils – Factors Considered in the Field Work Plan. Moisture content is a critical parameter and needs to be controlled. Bulk samples and moisture content measurements will be taken during compaction of the materials. The IC roller will be used to compact three sections within a project. One section will include the optimum moisture content and the other two will be below and above the target moisture content in terms of how the IC roller's response is affected by moisture content during the compaction process.

- Aggregate base; three or more different aggregate materials between the 3 new construction projects. It is assumed that an aggregate base and engineered embankment or subbase will be available on each project.
    - Three moisture levels – optimum, below optimum, above optimum.
    - Varying support conditions – weak and strong; defined by material type and layer modulus.
- Foundation soils/embankment; multiple soils between the 3 new construction projects – It is assumed that multiple soil types will be encountered along the same type. Projects will be selected to cover typical soils and soil conditions encountered in Wisconsin.
    - Three moisture levels – optimum, below optimum, above optimum.
    - Ground water table – high (water being pumped to surface is possible) and low (water being pumped to surface is improbable).

HMA Mixtures – Factors Considered in the Field Work Plan. Temperature is a critical parameter and needs to be controlled during compaction. Measurements will be taken over a temperature regime – temperatures above, within, and below the so-called temperature sensitive zone of HMA mixtures. It is expected that some of the HMA mixtures selected will exhibit temperature sensitive characteristics. The IC roller will be used to compact two sections within a project. One rolling zone will be a section and each section will be about 300 to 400 feet in length. At least two rolling zones or sections will be used for each set of conditions. One rolling zone will be compacted at a higher starting temperature, while the second rolling zone will be compacted at a lower temperature. This feature will identify different responses of the IC roller caused by temperature. Both of these starting temperatures need to be within the specifications set forth in project's construction documents or specifications. It is planned that some of the mixtures will exhibit checking to determine the measured responses of the IC roller in relation to the typical drop in density and stiffness within the temperature sensitive zone with continued rolling. The work plan assumes two HMA layers per project and that HMA lift thickness will follow WisDOT specifications (dependent on nominal maximum aggregate size), as noted below:

- HMA wearing surface – thinner lift and smaller aggregate size (finer mixtures).
- HMA base mixture – thicker lift and larger aggregate size (coarser mixtures).

Task 4 Prepare and Submit Interim Report

An interim report will be prepared and submitted so that the TOC can review and provide comments on the preliminary field work plan. The interim report will include a detailed layout of each project showing the individual sections or rolling zones planned. The field work plan will be presented to the TOC near the end of Task 4 – about 1-month after interim report submission to allow time for review. Revisions recommended by the TOC will be responded to and included in the final work plan submitted at the end of Task 4.

Task 5 Conduct the Field Work Plan

The work plan approved within Task 4 will be conducted in this task. The field team will consist of both ARA and UWM field personnel. It should be noted that some modifications to the preliminary field plan (Task 3) are expected based on input from the contractor and district personnel. The following is an itemized listing or summary of the actual field work planned for each project and material to be compacted using the IC rollers. These steps will occur after the projects have been initially selected from Task 2 and the contractor and district personnel agree to the preliminary field plan prepared under Task 3.

1. The project team will meet with the contractor and DOT field personnel to overview the schedule and field activities for the project (as part of Tasks 2 and 3). The coordination meeting will likely consist of multiple meetings during the course of this project and the paving projects. Our goal is to ensure that the contractor, as well as district personnel, is aware of our planned activities and field tests during construction. We want to minimize or eliminate the number of surprises from all parties regarding the field work plan.

2. The NDT devices or test methods and instrumentation to be used in the field test plan includes: nuclear density gauges, non-nuclear density gauges, stiffness measuring gauges (Geogauge for unbound materials and the portable seismic pavement analyzer [PSPA] for HMA mixtures), and the dynamic cone penetrometer (DCP) for the unbound layers. The DCP will only be used after compaction has been completed, because of the time required to perform the test on the unbound layers. All of these devices were used within NCHRP Project 10-65.

   The non-nuclear density gauges and the stiffness gauges will be used to measure the density and stiffness-growth curves as the rollers compact the material with successive passes of the rollers. We can have as many as two gauges on each project to ensure that an adequate number of readings are taken during compaction. The number of personnel and gauges on site will depend on the contractor's schedule and specific rolling pattern.

   These readings will be compared to the average IC roller response readings over a specific area and width of the paving lane. The IC roller responses will be recorded through the instrumentation on each roller. An IC roller kit (use and attachment of accelerometers on the vibratory drum) will be used, if the roller manufacturer does not provide the actual response output, as well as an estimate of the layer stiffness from their specific devices.

   The moisture content of the unbound materials and soils will be estimated using the nuclear density gauge readings and values measured in the laboratory on bulk material sampled during compaction. The surface temperature of the HMA will be measured with multiple devices, including infrared and traditional temperature gauges, as well as using the non-nuclear gauges.

3. Sample bulk material from the paving layer for measuring the resilient modulus of unbound materials

and the dynamic modulus for HMA mixtures. Test specimens for the resilient modulus tests will be prepared at the water content measured on the in place material/soil and compacted to the density measured on the in place material. The dynamic modulus of the HMA mixture will be measured in the laboratory on test specimen prepared from loose bulk mixture compacted to the in place density and air voids.

4. It is expected that a series of sublots will be identified that will coincide with the quality control and acceptance tests sublots, if at all possible. This decision will dependent on the project site features and contractor's schedule. The IC roller response and NDT devices response will be collected after each roller pass over a specific width (the width of the roller). Three point readings with the NDT devices will be measured on the layer's surface across the width of the vibratory drum (staying away from the ends of the drum). The measured roller response will be recorded for that specific length or area of paving. Two to four areas within a sublot will be used depending on the site features and contractor schedule. These details will be determined during the initial coordination meeting for each project.

5. The measured response of the vibratory roller will be compared to the relative compaction and modulus of the materials under successive passes of the roller using the other NDT devices. The final measured response of the material (density and modulus) will be measured after all rolling has been completed. These final values will be compared to the values measured in the laboratory at compatible conditions (temperature, moisture content, stress state, frequency, etc.).

Our work plan assumes that one project will be completed within a calendar month or less. The contractor (paving or foundation) will be contacted to schedule the field work and use of the IC rollers. Although a calendar month has been assumed, the actual work and field testing will take much less time. The following provides more detailed discussion on the sublots or sections that are planned for each project and lot in monitoring the IC roller response and output, response of the material being measured with multiple NDT devices, and densification of the paving material. The number of sublots to be used will depend on the number of IC rollers available for each project and material. One lane or line can be the standard rolling pattern and rollers being used by the contractor on the specific project and material.

- The width of each lane will be the width of the IC roller and the length will be for a compaction zone, about 400 feet.
- The response of the IC roller will be taken measured along each lane or line, as shown in figure 1.
- After each pass of the IC roller, the NDT devices will be used to measure the modulus and density of the material. The density and modulus growth curves will be constructed from this data.
- The output from each IC roller will also be used to judge or determine when the material has achieved the specified density level or specified response.
- After the final pass, the NDT devices will be used to take the final measurements within that lane or line. If it is found that the specifications have not been met, the roller will continue to compact the material until the minimum specifications have been met or the contractor's roller pattern will be used within that line or lane. If a different pattern is needed, the NDT devices will be used to take measurements during and after the standard roller pattern.

A detailed plan will be prepared for each project and paving material used within that project. A schematic will be prepared showing the specific areas to be used to monitor the materials response and the IC roller's response, as shown below. It is expected that one lane or line of rolling will be used by each roller, assuming that there is sufficient width for each IC roller used on the project. One lane or line could also be designated as the standard compaction train or rolling patter (roller types and number of passes) being used by the contractor to meet WisDOT's specifications.

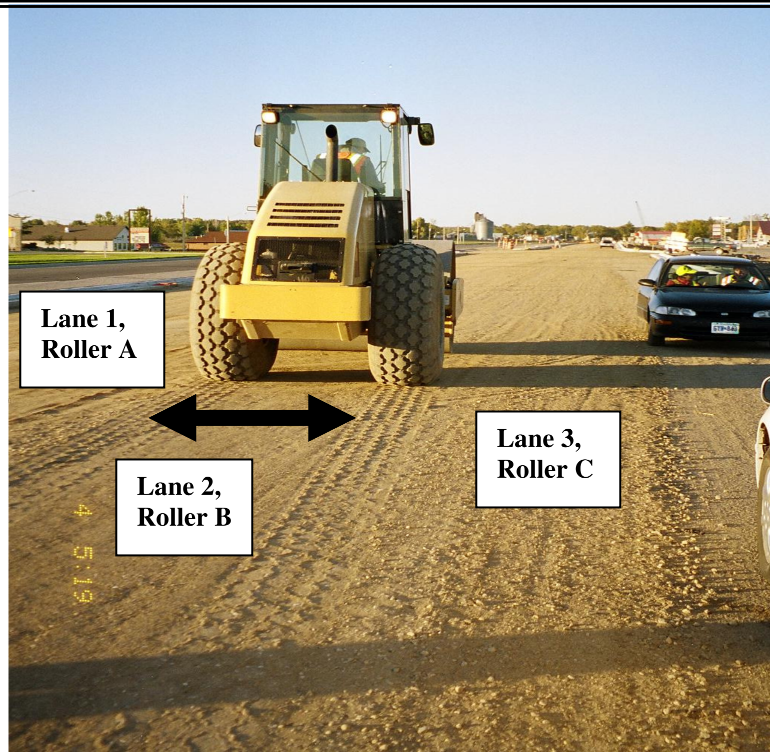


Figure 1. Example of the different lanes or lines that will be located on the surface of the material being compacted and testing with the IC rollers. Each IC roller used on a project and for a specific material will use a single lane or line within one rolling zone – defined as a sublot or test section for this research project.

The number of test sections or lots used will be discussed with both the contractor and WisDOT project personnel. The preliminary field work plan will include multiple lots or test sections within a project for each paving material. Figure 2 shows the layout of the different test sections or lots and sublots of the unbound aggregate layer that will dependent on the number of IC rollers available for each project and material.

The condition of the aggregate layer or soil within each lot (as illustrated in figure 2) will be discussed with the contractor and WisDOT personnel to ensure that the contractor can meet the project specifications and will not be penalized for participation on this project.

Figure 3 illustrates the test sections or lots and sublots for the HMA mixtures, as an example. The difference that is planned between each lot is the temperature of the mix. This condition will be discussed carefully with both the contractor and WisDOT personnel to ensure that the project specifications can be met. The surface temperature of the HMA mix will be closely monitored to ensure that adequate densities can be obtained. The width of all sublots added together will be equal to the width of the lift being placed in one pass of the paver.

The lower mix temperature could be a problem, especially if the HMA mixture has a wide temperature sensitive zone. If that is the case, only two temperatures might be used. The specifics of mixture condition will be discussed with the contractor to ensure that the specifications can be meet and an adequate density obtained after compaction.

The type of test equipment that is planned for use is listed below by material type.

- ***HMA mixtures:*** ARA staff will be responsible for all testing and work related to HMA mixtures.
    1. The nuclear density gauge will be the standard, as noted in the RFP. Non-nuclear density gauges will also be used, if WisDOT is planning to pursue use of these non-nuclear gauges for density control.
    2. Other tests planned for use include temperature and seismic tests for measuring stiffness growth curves in comparison to the IC roller's response. NCHRP Project 10-65 found reasonable correspondence between these measurements.
    3. Cores will be recovered from each roller zone in selected areas. It is expected that the core density measurements will be recovered from typical control or acceptance tests to minimize project costs.
    4. Bulk mixture will be sampled during placement to prepare test specimens for measuring dynamic modulus. Test specimens will be compacted to the average in-place air voids. This testing will be used to make the adjustment to in-place conditions under the rollers.
    5. Density and stiffness-growth curves will be prepared for the IC roller using the different devices – nuclear and non-nuclear density gauges, as well as seismic tests, and these values compared to the IC roller calculated stiffness or modulus values.
    6. QA (control and acceptance tests) data will be used for all volumetric properties of the different HMA mixtures.

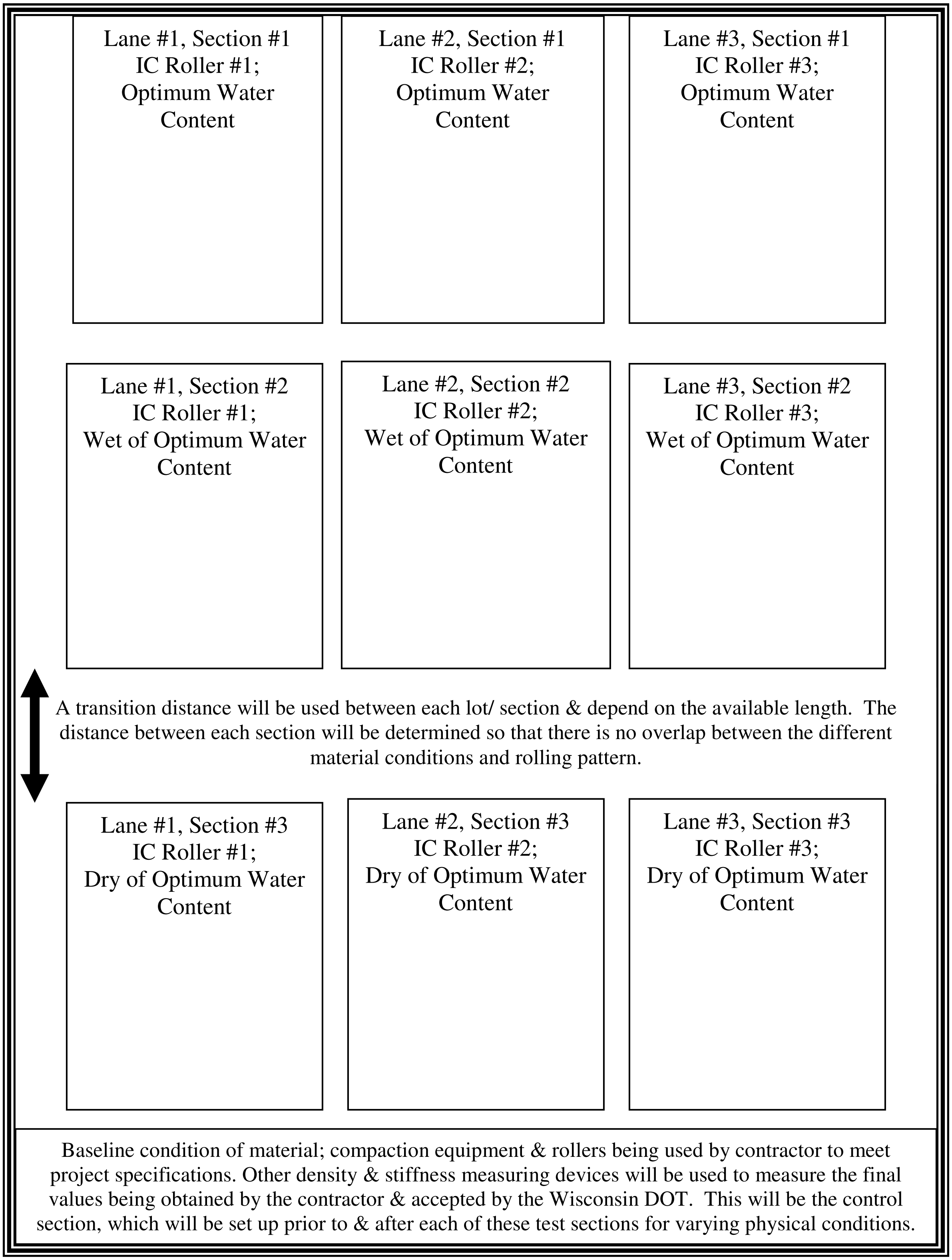


Figure 2. Schematic layout of the different test sections or lots/sublots that are planned for the unbound material or layer at a specific project.

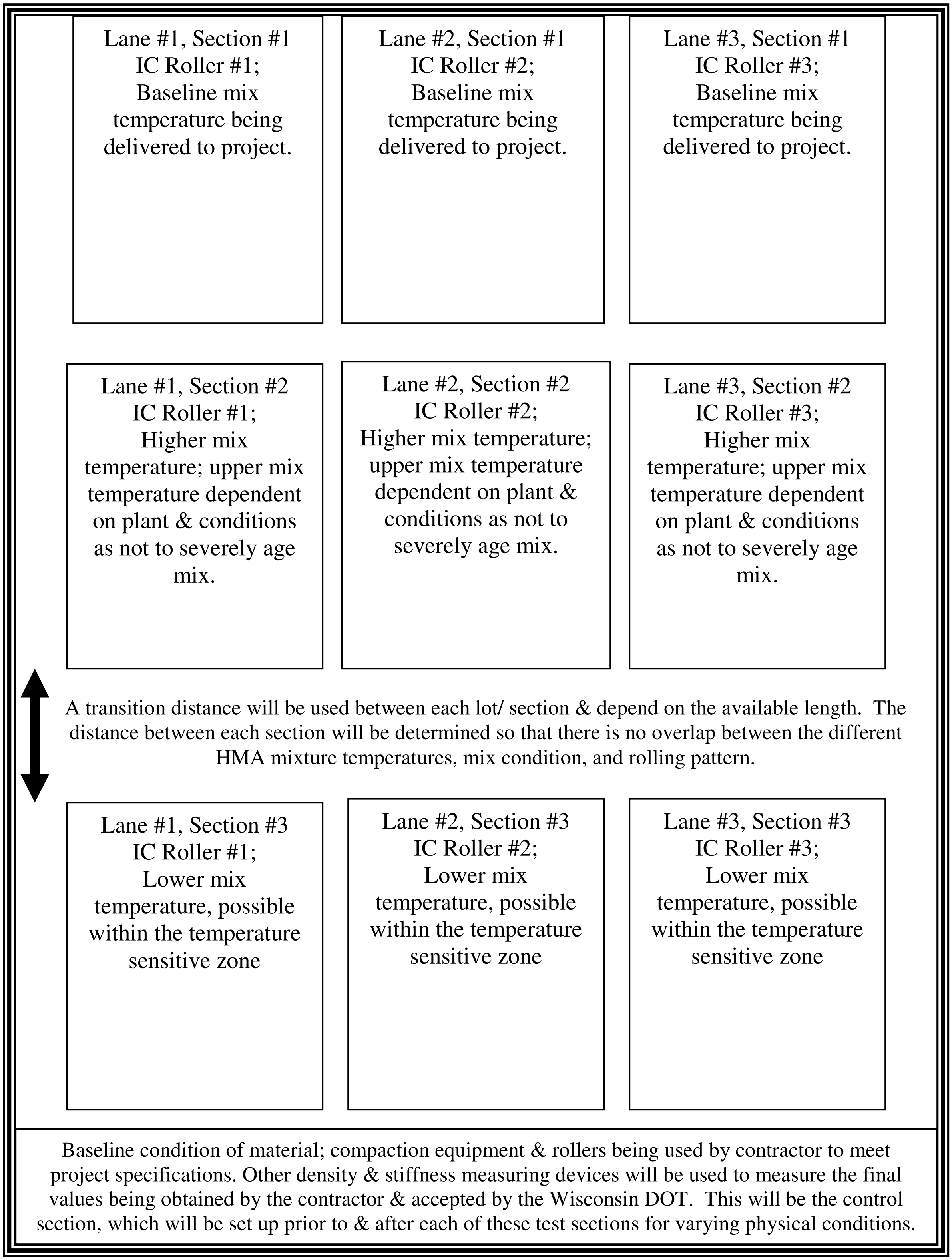


Figure 3. Schematic layout of the different test sections or lots/sublots that are planned for the HMA mixture or layer at a specific project.

- ***Unbound Aggregate Base Material or Foundation Soil:*** UWM will be responsible for all work related to unbound aggregate bases and embankment soils.

1. The nuclear density gauge will be the standard, as noted in the RFP.
2. Moisture contents will be measured on bulk materials sampled from each section or compaction zone. Oven-dried and nuclear values, as well as values measured with other NDT devices will be used. The NDT device selected will be based on results from Task 1, if found to be as reliable as the nuclear values.
3. The Geogauge will be used to measure the resilient modulus and compared to the IC roller's output.
4. Bulk material will be sampled during placement to prepare test specimens for measuring the resilient modulus. Test specimens will be compacted to the average in-place moisture content and dry density.
5. Density and stiffness-growth curves will be prepared under the IC roller using the different devices – nuclear gauges and the Geogauge, and compared to the IC roller calculated stiffness values.
6. QA tests and data for all volumetric properties of the different unbound materials included in the field experimental program.

The project team will monitor the densification process by the IC rollers in multiple locations. The non-nuclear density gauges will be used to measure the relative percent compaction and stiffness gauges will be used to measure the increase in modulus with number of passes of the IC roller. The IC roller response will be correlated to these other measurements, as well as the final density measured on the HMA cores recovered from the project and nuclear density readings. These other gauges will be used because of their accuracy and speed of operation in taking measurements as not to delay the compaction operation.

Task 6 Laboratory Testing

Limited laboratory tests will be completed on the materials sampled within each rolling zone or section. These laboratory tests include moisture contents and resilient modulus of unbound materials and soils, and dynamic modulus of HMA mixtures. The results from the laboratory testing will be used to adjust the field measured modulus values with the seismic and Geogauge, in accordance with the procedure used in NCHRP Project 10-65.

Task 7 Analyze Data from Field and Laboratory Tests and Provide Recommendations

The data analysis will be straight forward to identify systematic differences between the IC responses and output values and those measured with other NDT devices. This process will require developing correlation between IC outputs and lab modulus of the material being compacted. Based on knowledge of current technology and rapid test methods, the project team is of the opinion that a direct correlation cannot be achieved through simple means. Instead, the use of nondestructive testing (NDT) methods, that also offer a rapid testing alternative, would provide the necessary link between field and lab parameters.

Results from various research projects in which the project team is involved suggest that the Portable Seismic Pavement Analyzer (PSPA) and the Geogauge are suitable devices for HMA and unbound layers, respectively. As part of this project, a field/lab calibration will need to be developed which involves a three-step process listed below.

1. Develop an initial correlation between lab modulus and NDT device measurements.
2. Develop a field calibration between IC outputs and NDT device measurements on a controlled strip.
3. Derive a correlation between IC output & lab modulus from results of steps 1 and 2.

Additionally, the calibration process will consider effect of temperature and moisture on stiffness for specific materials. Therefore, the project team believes that it is important to isolate the effect of material compaction on apparent increase in stiffness recording and exclude the confounding effects of moisture and temperature for unbound and HMA layers, respectively. In other words, the calibration process will:

- Ensure increase in HMA stiffness is not caused by reduced temperature rather than increased density.
- Ensure increase in soil stiffness is not caused by reduced moisture content rather than higher density.

This can be achieved by determining the relationship in the laboratory testing process under controlled conditions to consider the effect of moisture on unbound layer density (and modulus) and the effect of temperature on HMA modulus.

The following lists the analyses and comparisons that will be performed between the different data sets:

1. Correlate test results between IC response outputs and layer properties measured by other NDT devices. Linear or nonlinear regression studies will be used to determine the correlation between the IC response (equipment dependent) and other NDT responses measured during compaction, as well as the final density and other properties of the pavement layers. Figure 4 and 5 are examples of some correlations that have been found on other projects.
2. Evaluate the effect of temperature and material condition on HMA responses of the IC roller.
3. Evaluate effect of moisture content and material condition on unbound material responses of the IC roller.
4. The IC compaction effort will be compared to the standard compaction effort being used by the contractor to compact different materials to determine which one is more efficient and reliable. The mean density and variances of density between the rolling zones compacted with and without use of the IC rollers will be evaluated to determine the most efficient process and confirm previous findings. In addition, the mean and variance of the modulus values measured with other NDT devices will be determined and compared between the standard rolling pattern being used by the contractor and the pattern using the IC roller (refer to figures 4 and 5, as some examples).
5. Based on the above comparative analyses, criteria (output values) that can be used by the roller operator to know when adequate compaction has been achieved and parameters that affect those critical values will be determined, if found to be statistically different. In addition, recommendations will be made to WisDOT and based on the analyses of this data for future use of IC technology; the accuracy, validity, and any limitations of that technology. The recommendations will include, as part of a QA program, the measurement of moisture in unbound layers and temperature of HMA layers and calibration (adjustment factors) of the output to match NDT and laboratory measured values, if needed.

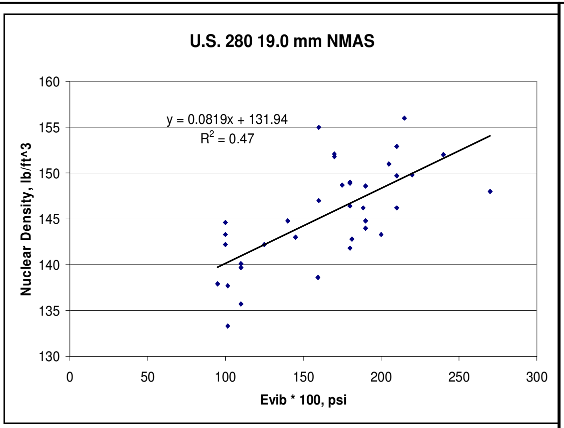


Figure 4. Comparison of the nuclear density readings to the E_{vib} values measured with the IC roller.

Figure 5. Example of a densification growth curve prepared from the IC roller demonstration and NDT test results.

Task 8 Prepare and Submit Draft Final and Final Report

A draft final and final report will be prepared and submitted to WHRP for review. These documents and their contents are discussed in Section 8.0 of our proposal.

Task 9 Presentations and Meeting Attendance
Both the PI and Co-PI will attend three planned meetings and make presentations to the TOC; a kick-off meeting that will occur at the end of Task 1, a meeting to present the interim report near the end of Task 4, and a meeting to present the draft final report and recommendations from this study within Task 8.

7.0 WORK TIME SCHEDULE

The timeline for each of the tasks outlined in the research plan is shown in Figure 9. The total amount of time required to complete the project is 24 months, including a 2- to 3-month period for review of project submittals, and a 2-month period for revising and submitting the final report. Our work plan assumes that all field work under Task 5 will be conducted during the 2008 construction season, assuming that this project is awarded in October 2007.

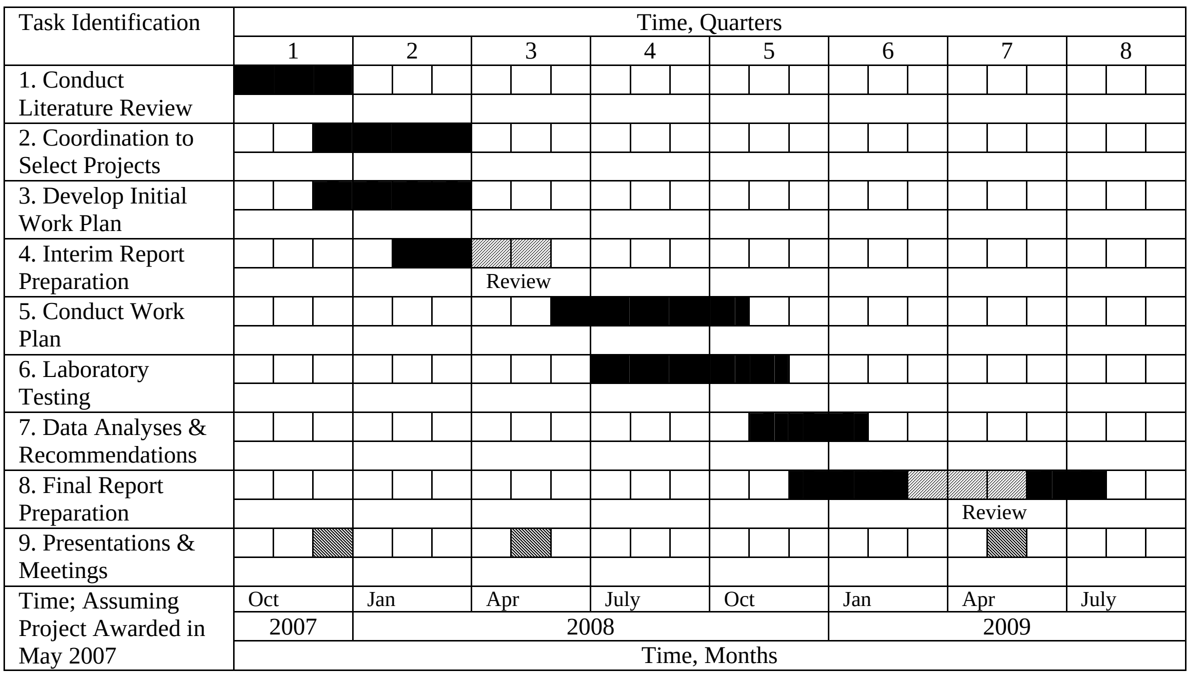


Figure 9. Schedule and Proposed Timeline for the Project

8.0 REPORTS AND PRODUCTS

The expected products from this study include reports and a training course. The training course will be prepared so that industry and WisDOT can continue with the implementation and training efforts after this study has been completed. The reports prepared as a part of this research effort are listed below:

1. Quarterly progress reports will be prepared and submitted during the course of the study.
2. An interim report will be submitted for review at the end of Task 3, so that the TOC can review and respond to the preliminary work plan.
3. A draft and final research report documenting the results of the entire study will be prepared and submitted for review within 17 months following the project start date. This report will include a summary of all project activities, and provide recommendations to the WisDOT and industry on the use of IC technology for controlling and improving pavement construction. The final report will include an appendix detailing all the projects and data collected within the study. The formal training course will be submitted within an appendix to the final research report.
4. A fourth document will be prepared as a standalone document, and included as an appendix to the final research report. This document will provide specific recommendations for implementing the IC technology in Wisconsin including; an implementation plan, suggested modifications to the construction specifications, and quality assurance guidelines for acceptance when using IC rollers on a project.

10.0 QUALIFICATIONS OF THE RESEARCH TEAM

Figure 10 shows the project management, organizational chart for this project. ARA will be the prime contractor to WHRP and the University of Wisconsin at Milwaukee (UWM) will be a subcontractor to ARA. Mr. Harold L. Von Quintus, Ahmad Ardani, and Chetana Rao will be the key members of the ARA team, while Drs. Sam Helwany and Hani Titi will be the key staff from UWM. To the best of our knowledge, we have nothing to disclose regarding interests that would impair objectivity as a result of past, present, or planned interests in organizations regulated by the DOT or in organizations whose interests may be substantially affected by Departmental activities.

In summary, Mr. Von Quintus (ARA) will be the Principal Investigator and have overall responsibility for the entire project, while Dr. Sam Helwany (UWM) will be the Co-Principal Investigator. Mr. Von Quintus and Ms. Rao will oversee all of the HMA work, while Dr. Helwany will oversee the geotechnical work. Mr. Ahmad Ardani (ARA) will serve as an expert on IC implementation and assist in preparing the recommendations from the field test results. Mr. Ardani will also be involved in preparing the implementation plan and in reviewing the recommendations made to Wisconsin from this study. Mr. Paul Rennels will be the ARA on-site field technician and Chetana Rao will be ARA's project manager and help direct the data analyses. Dr. Hani Titi will assist Dr. Helwany in the work being completed by UWM. In addition, a UWM research assistant and other staff will assist in the field work of Task 5 and laboratory tests of Task 6. Brief summarizes on the qualifications and previous experience of the research team, as related to this project, are provided in the following paragraphs. Professional resumes for the key ARA staff are provided at the end of our proposal.

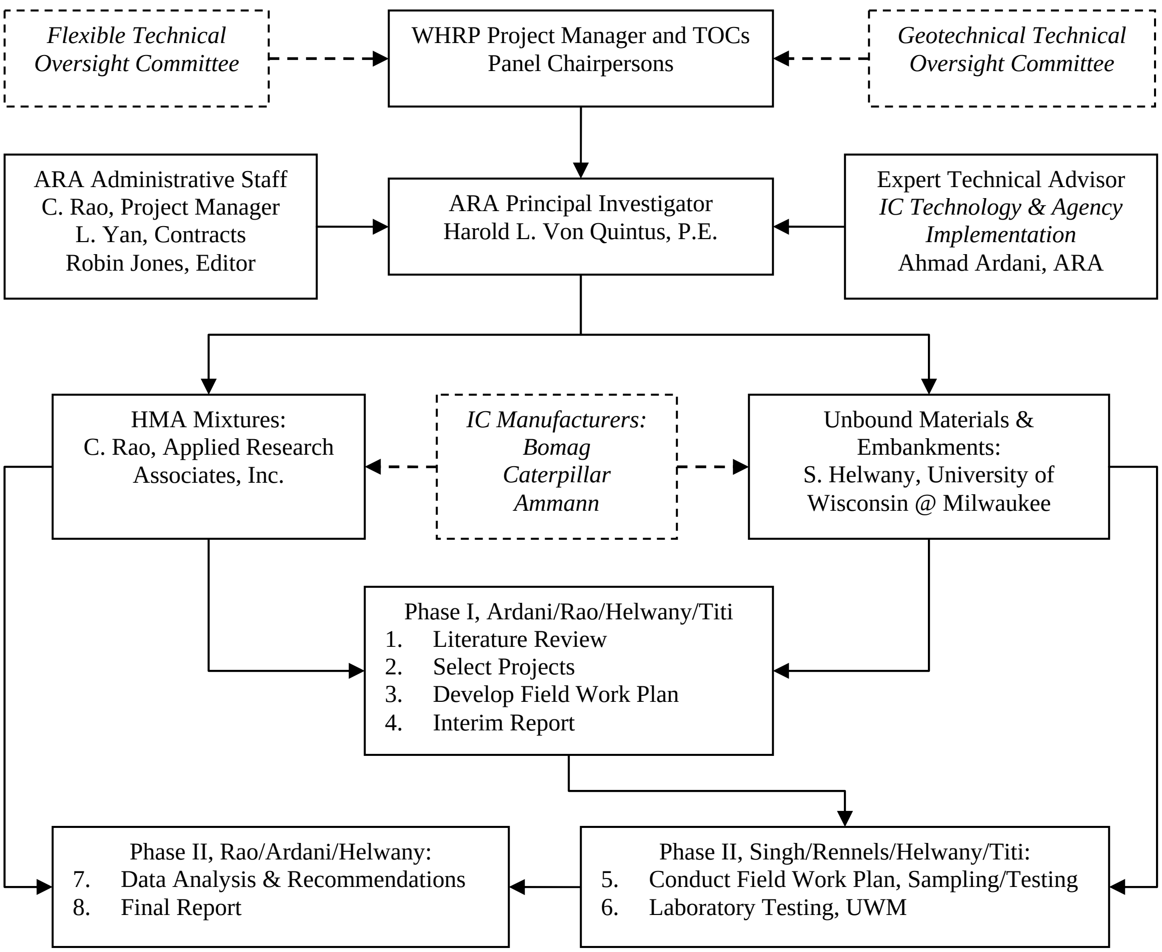


Figure 10. Project Management and Organizational Chart for the IC Technology Study.

<u>Mr. Harold L. Von Quintus, P.E. – Principal Investigator; ARA</u>

Mr. Von Quintus will be the Principal Investigator, responsible for all technical management and day-to-day activities to ensure that all tasks and work elements of the project are performed efficiently and completed in a timely manner. He has successfully carried out similar responsibilities as the Principal or Co-Principal Investigator for several FHWA and NCHRP projects that involved the review, collection, experimental design, and analysis of pavement and materials testing data, as well as construction of pavement test sections.

Mr. Von Quintus joined ARA-Transportation sector on April 29, 2002, and currently serves as a Principal Engineer 2. Prior to joining ARA, Mr. Von Quintus was an owner of Brent Rauhut Engineering (BRE), Inc. He joined BRE in January 1980 and became president of the company on July 1, 1985. In April 1996, he resigned as President and was elected as a Director on BRE's Board of Directors, until the company was sold to Fugro-USA in November 1997. From November 1997 until joining ARA he was a senior research engineer and responsible for most of the research projects.

Mr. Von Quintus was the PI on NCHRP Project 10-65 (*Nondestructive Testing Technology for Quality Control and Acceptance of Flexible Pavement Construction*) which involves the identification and evaluation of various NDT technologies for immediate application in flexible pavement construction. IC rollers were included in some of the field projects within that study. In Phase I of this project, completed in 2004, the project team conducted a thorough review of State QA practices, performance measures, and NDT technologies and devices that can be effectively applied in QC, acceptance, and independent verification programs. Phase II of this study focused on the evaluation of these technologies through field tests and the development of AASHTO standards and specifications for implementing these technologies. Mr. Von Quintus's experience and involvement in this project will have a direct and positive impact on the proposed WisDOT study.

In addition, Mr. Von Quintus has led numerous forensic and evaluation studies that have used various NDT technologies for evaluating HMA pavements. As an example, Mr. Von Quintus served as a technical expert on WHRP Project 0092-05-06, "*Non-Nuclear Density Testing Devices and Systems to Evaluate In-Place Asphalt Pavement Density*" to recommend the use of non-nuclear density testing methods for Wisconsin DOT. In a recent Georgia DOT project, he used GPR techniques to evaluate 130 lane miles of Atlanta Downtown connector and identify stripping in asphalt layers of the pavement. Mr. Von Quintus has been the Principal Investigator and/or Project Manager for numerous pavement research design projects across the U.S. Mr. Von Quintus led the NCHRP Project 9-30 effort (*Experimental Plan for Calibration and Validation of Hot-Mix Asphalt Performance Models for Mix and Structural Design*), and is the PI on NCHRP Project 9-30A (*Calibration of Rutting Models for HMA Structural and Mix Design*), both of which involve tying material properties to field performance and construction.

More recently, Mr. Von Quintus has served as one of the key team members on NCHRP Project 1-37A (*Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures*), the product of which is commonly known as the Mechanistic-Empirical Pavement Design Guide (MEPDG). Under NCHRP 1-37A, Mr. Von Quintus was actively involved in all activities related to the development of the traffic module, development of the calibration and validation plan for the flexible pavement distress prediction models, and enhancement of the ride quality prediction model from surface distresses. He was one of the team members involved in developing the experimental factorials for the calibration and validation of the distress prediction models. He is also actively involved in the implementation activities of the MEPDG. He serves as the PI on NCHRP Project 1-40B (*User Manual and Local Calibration Guide for the Mechanistic-Empirical Pavement Design Guide and Software*). In addition, he is assisting several State agencies (Montana, Missouri, Utah, Mississippi, etc.) in developing a road map and in implementing the MEPDG for their local conditions.

Mr. Von Quintus was also one of two Co-Principal Investigators on NCHRP Project 9-19, *Superpave Support and Performance Models Management*. On this project he was a team leader for the field validation of the simple performance test. Some of the other research projects that required the same areas of expertise identified in this research statement are listed below and were completed under his employment with other organizations.

- The AAMAS (Asphalt-Aggregate Mixture Analysis System) project documented in NCHRP Report 338 and dated November 1991. The AAMAS project laid much of the groundwork for the SHRP asphalt research program.

- Mr. Von Quintus has been actively involved in various aspects of the LTPP program. His specific involvement in this program included serving as the Quality Assurance Manager of the Southern Regional Coordination Office contract from 1988 to1992 and performing many of the analyses related to materials characterization and pavement performance data. Near the end of 1998, Mr. Von Quintus became the Co-Principal Investigator of the LTPP DATS contract sponsored by FHWA under a subcontract with ARA.

- Analysis Relating to Pavement Materials Characterizations and Their Effects on Pavement Performance, report dated October 1997. Mr. Von Quintus was the Principal Investigator for this project, which was one of the first data analysis contracts sponsored by FHWA in the materials characterization area for pavement design. Results from this project showed the importance of reviewing the data in the LTPP database to identify discrepancies and anomalies, which lead to the initiation of data studies to improve the overall quality of the LTPP database. The project also resulted in three design pamphlets to enhance the implementation and use of the 1993 AASHTO Design Guide through improved materials characterization and the use of mechanistic-empirical techniques for flexible pavement design.

- Study of Laboratory Resilient Modulus Test Data and Response Characteristics, draft report dated January 2001. Mr. Von Quintus was the Principal Investigator for this project and directed the detailed review and statistical analysis of the LTPP resilient modulus test data for all unbound pavement materials and soils. Results from this project identified that sampling technique (auger versus test pit aggregate base/subbase samples and undisturbed versus re-compacted soil samples) had a significant effect on the measured response of some materials and soils. This finding is important relative to the future use and analyze of the resilient modulus test data.

Chetana Rao—Project Manager/Engineer, ARA

Dr. Rao is a senior research engineer with ARA Transportation Sector and assigned as a project manager on this project. She holds a Ph.D. in Civil Engineering with specialization in pavements from the University of Illinois and has also worked in bridge engineering during her Masters and her previous consulting experience. Her main areas of expertise include analysis and design of highway structures, pavement material characterization, theoretical and field investigation of thermal and moisture effects in pavements, image analysis techniques, nondestructive evaluation, finite element modeling, and applications of artificial intelligence techniques to civil engineering. The following lists some of the projects that have similar activities to this project.

- Project Manager, NCHRP 10-65, *Nondestructive Testing Technology for Quality Control and Acceptance of Flexible Pavement Construction* (Ongoing project) – Dr. Rao played a key role in coordinating with several State agencies to collect information on their QA programs and in their experience in using NDT technologies for QC/QA, rehabilitation design, forensics, and research practices. She was also involved in identifying technologies that were promising for use in construction programs and was involved in field testing activities for earthwork and asphalt layers to evaluate selected devices all over the United States. The devices evaluated include the FWD, LWD, Geogauge, electrical density gage, GPR, non-nuclear density gage, and intelligent compaction.

- Project Manager and Co-PI from ARA, WHRP Project 0092-05-06, *Non-Nuclear Density Testing Devices and Systems to Evaluate In-Place Asphalt Pavement Density* – Dr. Rao was involved in developing a test plan and in coordinating field testing at 16 test sites all over the State of Wisconsin to evaluate the effectiveness of non-nuclear density testing methods for use in State QA practices. She played a key role in analyzing field data an in recommending field calibration methods that adequately met State specification requirements.

- Project Manager, FHWA DTFH61-05-D-00027, *Advanced Quality Systems TO 1 – Construction Quality Databases* – Dr. Rao was responsible to collect information from State agencies on their QA practices and their database programs and recommend a model construction quality database that can be used to store adequate construction data and be linked with other State databases such as performance and cost databases so that advanced analysis can be performed to track the effects of quality of construction performance and on life cycle costs.

While working at ARA, she has also worked on NCHRP Project 20-50 (09), *LTPP Data Analysis: Feasibility of Using FWD Deflection Data to Characterize Pavement Construction Quality*, analyzing LTPP rigid pavement test data to correlate FWD data with lab strength tests and construction quality. She has also been involved in the development of the calibration model for CRCP design for the NCHRP Project 1-37A, *Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures*. She has developed all software help tools and the implementation and training materials for this project. In addition, she has also served as a lead engineer on follow on implementation projects including NCHRP Projects 1-40B and 1-40D.

Ahmad Ardani – Principal Engineer/Technical Advisor, ARA

Mr. Ahmad Ardani, a Principal Engineer at ARA, will serve as a technical expert/advisor for this study. Prior to joining ARA, Mr. Ardani worked as the Program Manager for the Research Branch of the Colorado Department of Transportation (CDOT), heading up the Pavement and the Geotechnical Research Section of the CDOT's Research Branch and managed a multi-discipline national research program for CDOT called, Strategic Highway Research Program (SHRP). Mr. Ardani is well-known at the state and national levels for his published research papers and presentations on variety of technical subjects related to materials and pavement performance evaluations. Mr. Ardani has served as chair, study panel member, committee member and expert task group member for numerous research studies conducted at the national level for entities such as TRB, AASHTO, NCHRP and FHWA. Presently he serves as the chair of the NCHRP project 21-09, Intelligent Soil Compaction Systems. Mr. Ardani is the recipient of an AASHTO award for his leadership in developing and delivering the concept of "Corner State Demonstrations" for the AASHTO Lead State Program.

Paul Rennels – Field Technician, ARA

Mr. Paul Rennels is senior technician at ARA and brings extensive field experience to the project. He will perform the majority of the NDT tests (non-nuclear and seismic) during the field testing phase of the project and will be using the nuclear density gauge. He holds a certification to use the nuclear gauge (Nuclear Gauge Training Certification Nuclear Safety; Mixture Aggregate Course) and has performed testing for QC on the contractor’s side, QA for the State. He has also used several other devices (FWD, DCP, LWD, etc) on research and forensic evaluation projects.

Dr. Sam Helwany – Co-Principal Investigator, University of Wisconsin at Milwaukee

Dr. Sam M. Helwany will serve as the Co-Principal Investigator on the project. Dr. Helwany is an Associate Professor of geotechnical engineering at the University of Wisconsin Milwaukee. He obtained his Ph.D. in 1993 at the University of Colorado at Boulder. He obtained his MS degree in geotechnical engineering and his Bachelor degree of civil engineering at the University of Colorado-Denver. Dr. Helwany is a registered professional engineer. His main expertise is in the area of large-scale testing and numerical modeling of soil-structure interaction problems. He has conducted and analyzed numerous large-scale field and laboratory tests on soil structures subjected to static and dynamic loads. Dr. Helwany is currently involved in the following research projects: (1) Investigation of Vertical Members to Resist Surficial Slope Instabilities, Wisconsin Highway Research Program, 2004-2005, $29,714 (Helwany, Co-PI). (2) Development and Full Scale Testing of an Alternate Foundation System for Post and Panel Retaining Walls, Wisconsin Highway Research Program And Wisconsin Department Of Transportation, 2007-2008, $80,000 (Helwany, PI). (3) Construction Vibration Attenuation With Distance And Its

Effect On The Quality Of Early-Age Concrete, Wisconsin Highway Research Program And Wisconsin Department Of Transportation, HNTB, 2006-2007, $225,000 (Helwany, Co-PI).

Dr. Helwany has also worked on the following research projects: (1) Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin, Wisconsin Highway Research Program, $103,000 (Helwany, Co-PI). (2) Design and Construction of Geosynthetic Reinforced Soil (GRS) Abutments for Bridge Support, National Cooperative Highway Research Program, 2001-2003, $300,000, Helwany, Co-PI (with Dr. Wu, PI, and Dr. Tatsuoka, Co-PI). (3) Evaluation of the AASHTO 18-kip Equivalency Concept, 1996-98, $338,028, Sponsored by Texas Department of Transportation, Helwany, Co-PI (with Dr. Hudson, PI). (4) Dynamic Lateral Earth Pressure on Underground Structures, 1997-98, $125,000, Sponsored by Air Force Office for Scientific Research (AFOSR), Helwany, PI (with Drs. Ko, Pak, and Chowdhury, Co-PI's). (5) The Effects of Facing Rigidity on the Performance of GRS Structures. 1994, $125,000, This research project was sponsored by Japan Railways and performed at the Institute of Industrial Science-The University of Tokyo. The project involved the design of full-scale experiments and finite element analyses of geosynthetic-reinforced embankments for the "Bullet Train". (6) Pile Set-Up, Graduate School-UWM, 2000, $15,000 (Helwany, PI). (7) Evaluation of Bridge Approach Settlement Mitigation Techniques, Wisconsin Highway Research Program, 2000-2004, $100,000 (Helwany, PI). (8) Analysis and Design of Dies for Polymer Extrusion. UW Applied Research Program. 2004, $41,393 (Helwany, PI)

Dr. Hani Titi – Project Engineer, University of Wisconsin at Milwaukee

Dr. Titi is an Associate Professor in the Department of Civil Engineering and Mechanics at UW-Milwaukee and is a registered Professional Engineer. Dr. Titi has more that 18 years of experience in advanced experimental research and analysis, especially in problems related to pavements and geotechnical engineering. During his current position at UW-Milwaukee and previous position Louisiana Transportation Research Center and Louisiana Department of Transportation and Development, he conducted advanced research and served as PI and Co-PI for projects funded by different entities including: Wisconsin Highway Research Program (WHRP)/Wisconsin Department of Transportation, Minnesota Department of Transportation, Midwest Regional University Transportation Center, and Louisiana Department of Transportation and Development. The following are selected completed pavement related projects in which he was involved:

- Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin. Wisconsin Department of Transportation, Wisconsin Highway Research Program, ($103,049). PI: Dr. Hani Titi and Co-PI Dr. Sam Helwany.
- Mechanistic/Numerical Methodology for Improved Performance of Highway Pavements, UWM Graduate School Research Committee Award, ($14,901) PI: Dr. Hani Titi
- Guidelines for the Surface Preparation/Rehabilitation Of Existing Concrete and Asphaltic Pavements Prior to an Asphaltic Concrete Overlay. Wisconsin Department of Transportation, Wisconsin Highway Research Program, ($64,997). PI: Dr. Haifang Wen – Bloom Consultants. Co-PI: Dr. Hani Titi

Dr. Titi is a member of TRB committees (AFP20, AFP30, and AFS30), a member of NCHRP panel D2431, and the Secretary of the ASCE-Geo-Institute Pavement Engineering Committee. Dr. Titi is the author and co-author of more than 45 publications (journal, conference and research reports) in the area of geotechnical and pavement engineering. The following are selected pavement related publications:

1. Titi, H.H., Elias, M.B., and Helwany, S. (2006) "Determination of Typical Resilient Modulus Values for Selected Soils Representative of the Soils Distributions of Wisconsin," Research Report, Wisconsin Department of Transportation, Wisconsin Highway Research Program, Madison, WI.
2. Elias, M.B. and Titi, H.H. (2006). "Evaluation of Resilient Modulus Model Parameters for Mechanistic Empirical Pavement Design," Journal of the Transportation Research Board, No. 1967, Geology and Properties of Earth Materials 2006, Transportation Research Board, Washington, D.C., pp.89-100.
3. Wen, H., Titi, H.H., and Berry, D. (2006). "Study of Best Practices for Pre-Overlay Repair and Asphalt Overlay," Proceedings of the 2006 Airfield and Highway Pavement Specialty Conference, American

Society of Civil Engineers, Atlanta, GA, pp 815-823.
4. Elias, M.B., Titi, H.H., and Helwany, S. (2004) "Evaluation of Resilient Modulus of Typical Wisconsin Soils," Geotechnical Practice Publication No. 1, GeoJordan: Advances in Geotechnical Engineering with Emphasis on Dams, Highway Material, and Soil Improvement, American Society of Civil Engineers, pp. 335-346.
5. Rasoulian, M., Titi, H.H., and Martinez, M. (2005). "Evaluation of Narrow Transverse Contraction Joints in Jointed Plain Concrete Pavements," Proceedings of the International Conference on Concrete Pavements, Colorado Springs, Co, pp. 357-371.
6. Carroll, D.A., Cheng, R., Eger III, R., Grusczynski, L., Marlowe, J. and Titi, H. H. (2004). "Highway Preventive Maintenance Implementation: Comparing Challenges, Processes, and Solutions in Three States," Journal of the Transportation Research Board No. 1877, National Research Council, Washington, D.C., pp. 10-16.
7. Titi, H. H. (2004.) "Parameters of Jointed Plain Concrete Pavements for Customization of the HIPERPAV-Wisconsin System," Research Report Submitted to The Transtec Group, Inc., Austin, TX, p. 46.

11.0 FACILITIES AND EQUIPMENT

There is one subcontractor planned for this project; the University of Wisconsin at Milwaukee (UWM). UWM will be responsible for the geotechnical portion of this study and all laboratory testing. A brief description of ARA's and UWM's facilities and equipment is provided in this section. In addition, two of the equipment manufacturers (Caterpillar and Bomag) have agreed to provide one of their IC rollers for use in compacting the HMA mixtures, unbound pavement layers and embankment soils on the projects selected for this study. Specifically, ARA and UWM have a verbal agreement with these manufacturers to make their systems available for field testing operations (refer to Section 9.0). The IC rollers are being provided at no cost to the project, with the exception of covering the transportation costs of the equipment. Use of the equipment will be coordinated with the manufacturers in Task 2. In addition, ARA has secured the support of Humboldt for using the Geogauge to measure soil stiffness and modulus, and will lease a nuclear gauge for measuring the density of the HMA and unbound materials. Mr. Paul Rennels (ARA) is certified in using nuclear gauges for density testing.

11.1 Applied Research Associates, Inc.

ARA is an international research and engineering company recognized for providing technically excellent solutions to complex and challenging problems in the physical sciences. In the transportation community, this focus translates into providing innovative technologies and services in the areas of asset management, pavement management, nondestructive testing, equipment development and manufacture, pavement design and construction, and traffic monitoring. ARA's expertise in these areas allows agencies to better address the challenges they face in cost-effectively designing, building, maintaining, and preserving a network of horizontal infrastructure.

ARA has a broad range of technical expertise in civil engineering, computer software and simulation, systems analysis, data collection, technology transfer, and physical testing & measurement. ARA also provides sophisticated technical products for pavement evaluation, roadway asset inventory, traffic data collection, and robotics. ARA has offices in many areas of the U.S., including Wisconsin. Our staff now includes over 100 professionals operating in 10 cities—Champaign, Illinois; Columbia, Maryland; Vicksburg, Mississippi; Reno, Nevada; Ventura, California; Minneapolis, Minnesota; Overland Park, Kansas; Madison, Wisconsin; Round Rock, Texas; and Toronto, Ontario.

Pavement Research. ARA and their personnel have performed research projects in support of a wide range of clients, from various agencies of the Federal Government to State agencies and private industry. For example, ARA and the selected team members for this proposal have been involved in key pavement research projects such as NCHRP Projects 10-44, 10-65, 1-37A, 1-40B, 1-40D, 9-30, 9-30A, FHWA's Advanced Quality Systems, and several State agency projects in similar fields. ARA has been involved in the Long-Term Pavement Performance

(LTPP) Data Analysis contract by the FHWA for the analysis and interpretation of data collected as part of the SHRP program's national data collection efforts.

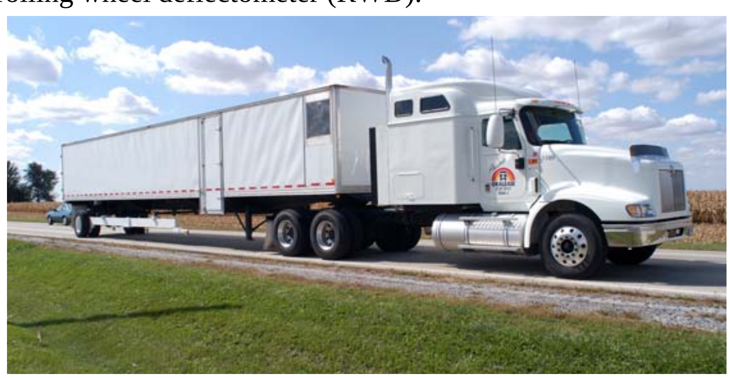
ARA has been involved in improving pavement performance through improved design, construction, materials, maintenance, and rehabilitation practices, as well as in identifying innovative materials and equipment. Among the pavement topics in which ARA has conducted research are asphalt and concrete pavement design, test methods, friction, smoothness, performance modeling, rehabilitation, soil stabilization, maintenance, and performance specifications. ARA is committed to the advancement of state-of-the-art technology, as well as to the implementation of that technology into practice.

Education and Training. ARA is a world leader in developing and teaching training courses dealing with all aspects of pavement design, construction, rehabilitation, and maintenance. We have developed courses for the National Highway Institute (NHI), AASHTO, State and municipal governments, and industry trade organizations. Our current offerings include more than two dozen courses, such as:

- Hot-Mix Asphalt Construction and HMA Materials; Mixtures, Characteristics and Control
- Introduction to Mechanistic-Empirical Pavement Procedures for Pavement Design
- Local Government Asset Management Best Practices
- Pavement Condition Surveys
- Pavement Subsurface Drainage Design
- AASHTO Procedures for New Pavement Design
- DARWin 3.1 Pavement Design Software
- Construction of Portland Cement Concrete Pavements
- Maintenance Quality Assurance
- Asphalt Pavement Preservation

ARA routinely provides training as part of pavement and asset management system implementation projects, instructing agency personnel how to perform field surveys and use the system software. In addition, we maintain a catalog of training modules for use in developing custom training programs and workshops. Training materials, including manuals and supplemental information, are also available. ARA's course instructors include our own engineers, university professors, and retired Federal and State highway engineers. They combine expertise in pavement engineering with outstanding teaching and communication abilities.

Pavement Evaluation and Data Collection Technologies. Visual condition surveys have been one of ARA's primary services since the beginning. ARA routinely perform condition surveys for network-level pavement management projects, as well as for some project-level applications. In addition to the visual condition assessment technologies discuss above, ARA owns and operates several state-of-the-art pavement evaluation devices. Included in our capabilities are a suite of falling weight deflectometers (FWDs), ground penetrating radar (GPR), automated cone penetrometers, and ARA's latest innovation, the rolling wheel deflectometer (RWD).



The RWD is a one-of-a-kind pavement testing device for the rapid evaluation of structural condition of highway networks. It is designed to measure pavement deflection beneath a moving wheel load in a safe and efficient manner. Unlike currently used stationary equipment, the RWD is capable of providing a continuous deflection profile and can operate at normal highway speeds. This allows the operator to collect and analyze up to 300 miles of road per day. Additionally, it does not require closing a lane for analysis and the number of workers needed for the project to be present on the highway decreases significantly by eliminating work zone safety issues.

ARA has over 20 years of experience in conducting inventory and condition assessment surveys of transportation infrastructure. We are experienced in collecting inventory data and performing condition assessment surveys for assets such as pavement signs, lighting, guardrail, curb & gutter, and other roadway, base, and airfield assets. ARA conducts surveys using traditional field crews, handheld data collection devices, and vehicle-mounted digital camera and spatial referencing systems.

11.2 University of Wisconsin at Milwaukee

UWM Library. The library has extensive collections of periodicals, literature, and related books. Materials that are not available in the UWM Library can be obtained through its Interlibrary Loan department. In addition, the Co-PI has access to the information retrieval files of technical literature abstracts such as TRIS and ASCE engineering database.

Geotechnical & Pavement Engineering Laboratories. The proposed research project will be conducted at the Geotechnical & Pavement Laboratory of the Department of Civil Engineering and Mechanics at UW-Milwaukee. The laboratory is equipped with the necessary instruments and tools to successfully accomplish the objective of the research project. The following is a description of the main equipment:

- ***Servo-hydraulic Dynamic Materials Testing System:*** Figure 11 shows a state of the art Instron FastTrack 8802 closed loop servo-hydraulic dynamic materials test system at UW-Milwaukee. The system utilizes 8800 Controller with four control channels of 19-bit resolution and data acquisition. A computer with FastTrack Console is the main user interface. This is a fully digital controlled system with adaptive control that allows continuous update of PID terms at 1 kHz, which automatically compensates for the specimen stiffness during repeated load testing. The loading frame capacity of the system is 250 kN (56 kip) with a series 3690 actuator that has a stroke of 150 mm (6 in.) and with a load capacity of 250 kN (56 kip). The system has two dynamic load cells 5 and 1 kN (1.1 and 0.22 kip) for measurement of the repeated applied load. The load cells include integral accelerometer to remove the effect of dynamic loading on the moving load cell. Triaxial cells with maximum sample diameter of 6 in. are also available.

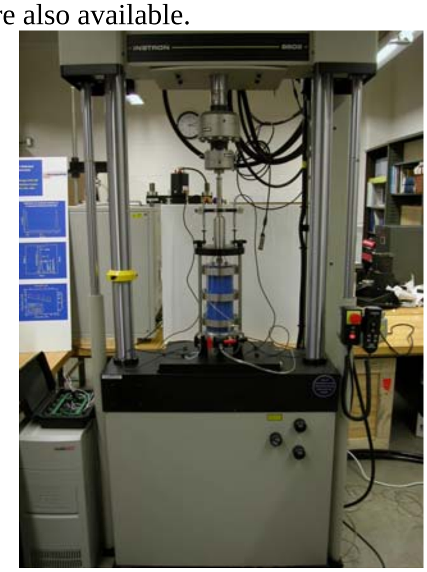


Figure 11. The UWM servo-hydraulic closed-loop dynamic materials test system

- ***Equipment for Measurement and Determination of Soil Properties:*** These include the following: Dynamic repeated load and static triaxial test, grain size analysis shakers (sieve analysis), temperature-controlled hydrometer path, specific gravity determination equipment, Atterberg limits (plastic and liquid limit of soils), automatic soil compactor (Standard and Modified Proctor test), digital-controlled ovens, automated direct shear test system, automated soil consolidation system, vibratory table for determination of relative density of cohesionless soils, unconfined compression test system, drying ovens, etc.

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